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Development of *p*-type silicon surface barrier detectors

R Saha and R P Sharma
Variable Energy Cyclotron Centre, DAE, 1/AF Bidhan Nagar, Calcutta-700 064, India

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Abstract : Fabrication techniques for *p*-type silicon surface barrier detectors have been described Application of evaporated germanium as a rectifying contact in place of aluminium is studied which resulted in the improvement of shelf life of *p*-type detectors.

Keywords : Silicon surface barrier, germanium contact, shelf life

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1. Introduction

Surface barrier detectors made from *n*-type silicon have been most successful. Nevertheless, several authors have reported fabrication of surface barrier detectors from *p*-type silicon. Among them the work of Mathew *et al* [1] and Chaudhry and Srikantiah [2] are of special significance as these were among the first few successful attempts in fabricating these devices. Fabrication of ultra-high purity *p*-type silicon surface barrier detectors have been described in references [3,4]. Some of the advantages of making *p*-type detectors are described below.

p-type silicon is available in purer form than *n*-type silicon since *n*-type material is produced by the overcompensation of *p*-type material, thus increasing the number of imperfections in the crystal structure. Silicon crystals of *p*-type can be grown with lower radial resistivity variation than those of *n*-type. The thickness of the depletion depth both in *n* and *p* type material is given by the following relations :

$$W_n = 0.53\,(\rho_n . V)^{1/2} \tag{1}$$

and

$$W_p = 0.32\,(\rho_p . V)^{1/2}, \tag{2}$$

where ρ's are the resistivities in ohm-cm, V is the applied reverse bias in volts and W's are the depletion depths in microns. Therefore, for a given resistivity and reverse bias the depletion depth in p-type is approximately half of that formed in n-type material. As a result of this the electric field intensity will be greater and will result in improved charge collection, an important factor in the spectroscopy of heavy charged particles. Because of the front aluminium contact these detectors are rugged and light tight.

Mathew *et al* [1] have reported the results of investigations for studying the nature of the junctions formed between p-type silicon and evaporated films of different metals for finding those most suitable for rectifying and ohmic contacts. Au, Ag, Cu, Cr, and Pt formed weak barrier layers, the junctions were unstable, got easily contaminated and the contacts became ohmic. Al, In and Mn formed strong barrier layers which could withstand large reverse biases. But In and Mn are not sufficiently stable to be suitable for detectors. Thus, the best results are obtained by using evaporated Al as rectifying contact and Au as ohmic contact.

In many applications, surface barrier type detectors are advantageous because of their high resolutions and very thin dead layers at the entrance. But, these detectors are less rugged and need to be handled with great care as they are susceptible to damage from exposure to ambient and evaporated metal may get wiped out causing serious deterioration of detector performance. The diffused junction silicon detectors have the advantage of being more rugged and less susceptible to ambient, their larger dead layer at the window as compared to surface barrier detectors can be a disadvantage in many applications. The ion implanted detectors can be made with very thin entrance windows. The ion implanted detectors are stable and less sensitive to ambient conditions and are therefore preferred when ruggedness is important. The ion implantation technology is used in the fabrication of modern silicon microstrip detectors [5].

2. Detector fabrication

The choice of the basic material has a strong influence on the quality of the fabricated detectors. The specifications of the silicon wafers used in our laboratory are as follows :

Type	:	P, boron doped
Resistivity	:	1000 – 5000 Ω cm
Minority carrier lifetime	:	>2000 μs
Oxygen content	:	$<10^{15}$ atoms cm^{-3}
Etch pit density	:	<500 cm^{-2}
Orientation	:	<111>

2.1. Wafer preparation :

p-type silicon single crystals in the form of cylindrical ingots are cut into the shape of circular discs of required thicknesses with the help of a semiautomatic diamond wheel saw. If required, these discs are cut into smaller discs by an abrasive slurry drill machine. The discs are then cleaned and lapped on both sides with the help of a lapping machine (Lapmaster–12). Each of the lapped discs is thoroughly cleaned by detergent solution and deionised water and then subjected to ultrasonic vibration by dipping in deionised water. Then the prepared wafers *i.e.*, the circular discs, are cleaned successively by boiling in trichloroethylene, methanol and deionised water. From this point, the discs are handled only with clean teflon tweezers.

2.2. Wafer etching :

Each of the two parallel surfaces of the disc is etched separately in a rotating bath of HNO_3 and HF mixed in the ratio of 20:1 by volume. The temperature of the etchant is maintained at about 0°C. The etching is terminated by adding deionised water to the etchant when the flat surface exposed to the etchant turns into a mirror ; half the diluted etchant is poured out. Then the etchant is further diluted by adding deionised water and again half the diluted etchant is poured out. This procedure of diluting is repeated at least ten times. The wafer is then thoroughly washed in deionised water and jet dried in pure nitrogen gas.

2.3. Edge protection :

The wafers are fixed in teflon insulated mounts with an epoxy. The edges of the front surface are coated with Epoxylite Resin #69 and *n*-type hardener (from M/s Epoxylite Corporation of America) mixed in the ratio of 5:2 by volume, whereas the back surface edges are coated with the same resin mixed with *p*-type hardener in the ratio of 10:1. The epoxy is cured under an infra-red lamp for a few hours.

2.4. Deposition of metallic contacts :

It has been found desirable to evaporate electrodes onto the wafers as soon as possible after etching in order to minimize the risk of surface contamination. A thin Al layer of about 20 $\mu g/cm^2$ is evaporated on the front surface of the wafer at a pressure of about 1×10^{-5} torr from a tungsten filament. This forms the rectifying contact of the detector. Similarly, a thin layer of Au of thickness 40 $\mu g/cm^2$ is deposited on the back surface of the wafer which forms the ohmic contact. The gold and aluminium wires used for evaporation are of 99.999% purity.

The detector is housed in a gold plated standard encapsulation having a Microdot connector at the back.

3. Performance of detectors

3.1. Leakage current measurement :

The detector is placed in a vacuum chamber for these measurements at a pressure of about 10^{-4} torr. A large number of *p*-type surface barrier detectors have been fabricated in our laboratory. In Figure 1 leakage current as a function of reverse bias is plotted for a typical p-type silicon surface barrier detector of active area 50 mm^2 and of thickness 225 μm. This detector exhibited an FWHM of 45 keV for 5.486 MeV alpha peak.

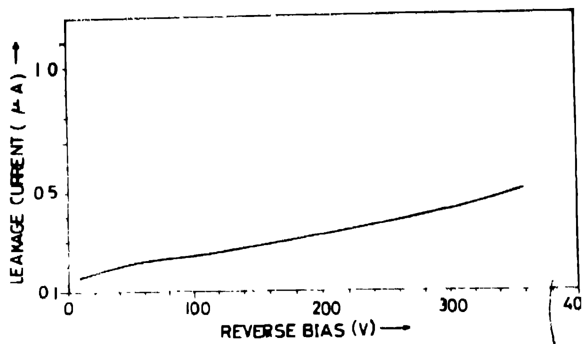

Figure 1. I-V characteristics of a p-type silicon surface barrier detector measured at 25°C.

3.2. Energy resolution measurement :

The p-type silicon surface barrier detector is kept along with an α-source of strength 0.1 μ Curie in a vacuum chamber at a pressure of 1×10^{-1} torr. The front surface of the detector is exposed to the α-source comprising ^{241}Am and ^{239}Pu α's from a distance of 20 to 25 mm The detector is connected to the pre-amplifier through a 'microdot to BNC' connector. The negative bias supply is slowly raised to the maximum permissible value for the detector. The maximum permissible value of bias voltage is that beyond which the detector resolution starts

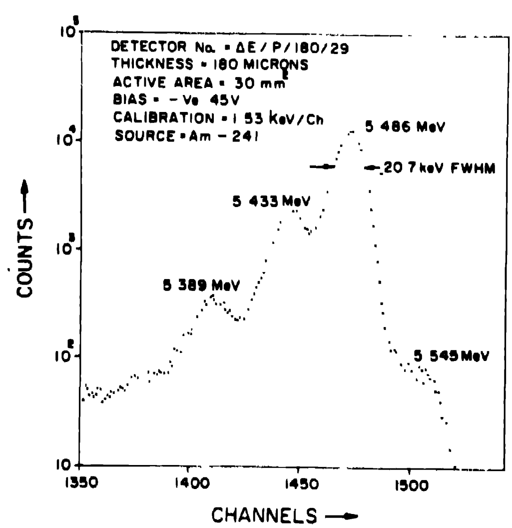

Figure 2. ^{241} Am alpha spectrum with a p-type surface barrier detector at room temperature and at 1×10^{-1} torr pressure.

getting deteriorated. As the quality of a detector is normally determined by its resolution, a detector is operated at such a bias at which its performance in respect of resolution is the best.

The maximum permissible value of bias voltage for a detector has no connection with whether the detector is fully depleted or not. Normally, in our laboratory the detector resolution is measured using a set of ORTEC pre-amplifier, detector bias supply, spectroscopy amplifier and 4k Canberra-88 series MCA. The Figure 2 shows the spectrum of ^{241}Am alphas, having a resolution of 20.7 keV at 5.486 MeV peak, obtained with a *p*-type silicon surface barrier detector by operating it at its maximum permissible value of bias voltage which was –ve 45 V only. Whereas the full depletion bias voltage for the same detector was –ve 360 V. The resolutions of the *p*-type detectors obtained for various thicknesses and active areas are given in Table 1.

Table 1. *p*-type detector resolution data for ^{241}Am alphas.

S no.	Detector thickness (μm)	Active area (mm^2)	FWHM (keV)	No. of detectors
1	40–60	10–50	36–58	7
2.	60–100	25–100	30–66	24
3.	100–150	10–100	30–72	19
4.	150–200	25–50	20–77	5
5.	200–250	25–75	38–70	4
6.	300–500	25–100	30–80	6
7.	500–700	30–60	30–50	4
			Total :	69

4. Germanium contacts

The Al contacts in silicon surface barrier detectors are found to degrade over a period of time due to aging effect [6,7] The same is true for the Al rectifying contacts in *p*-type silicon. England and Hammer [8] and Avdeichikov [9] described the application of Ge contacts to obviate the problem. Because of this instability of Al contacts, the average calculated shelf life of these detectors in our case, is about 15 months. Figure 3 gives the observed shelf lives of

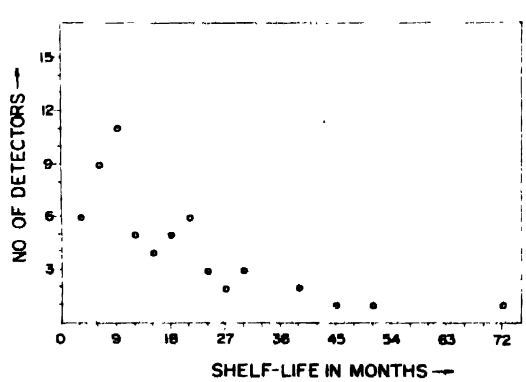

Figure 3. Shelf-life distribution of *p*-type silicon surface barrier detectors without sandwiched germanium layer.

different *p*-type detectors. Efforts have been made to improve the shelf life of *p*-type silicon surface barrier detectors. One such method consists of evaporating a thin amorphous germanium layer of thickness about 10 μg/cm^2 on one surface of the wafer at a slow rate of about 1 Angstrom/sec at a pressure of 1×10^{-5} torr [10]. Then a normal layer of aluminium is evaporated, as mentioned before, on the germanium layer to get a good metallic contact.

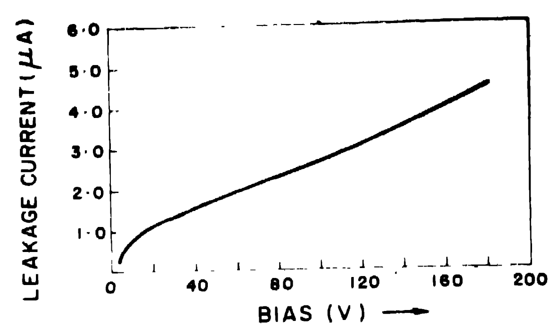

Figure 4. I-V characteristics of a germanium sandwiched p-type surface barrier detector fabricated of shelf age more than four years

Four detectors were fabricated using this technique. All the four detectors fabricated with a sandwiched layer of germanium have been found to have shelf life of more than four years. Figure 4 shows the I-V characteristics, measured at 25° C temperature and at 1×10^{-1} torr pressure, of such a four year old detector having 24 keV resolution for 5.486 MeV ^{241}Am alphas. Here, it is found that in spite of high leakage current the energy resolution is quite good. Efforts to minimize the leakage current and FWHM for such long lived detectors are on. The results of Ge contact *p*-type detectors have been reported in a symposium [11].

5. Conclusion

Because of the development of *p*-type detectors the handling of surface barrier detectors becomes much easier as there is no danger of accidental wiping of the aluminium layer unlike in the case of gold layer utilized in the fabrication of *n*-type silicon detectors. Also, because of the lower Z-value of the entrance aluminium contact, these detectors are increasingly finding the new role in soft X-ray flux measurement in hot plasma experiments. The improvement of shelf life by employing germanium sandwiched layer will go a long way in popularizing the use of *p*-type silicon surface barrier detectors.

But in terms of popularity, nothing is better than silicon microstrip detectors. Silicon microstrip detectors have recently gained increasing popularity owing to their superior spatial resolution. Typical spatial resolutions of the order of 5 μm have been achieved. And applications of these detectors are diverse, from their use as Vertex Detectors in CDF at Tevatron, LEP, Super Collider such as LHC and B-factories, to astrophysics.

References

[1] P J Mathew, N G Chapman and G E Coote *Nucl. Instrum. Meth.* **49** 245 (1967)

[2] R Chaudhry and R V Srikantiah *Surface Barrier Detectors from p-type silicon* BARC Report No. 527 (1971)

[3] F Shiraishi and Y Takami *Nucl. Instrum. Meth.* **196** 137 (1982)

[4] F Shiraishi, Y Takamu and M Hosoe *Nucl. Instrum. Meth.* **226** 107 (1984)

[5] S C Yeh, S Su and J P Lu *Nucl. Instrum. Meth* **A342** 49 (1994)

[6] P Siffert and A Coche *IEEE Trans. Nucl Sci.* **NS-12** 284 (1965)

[7] D C Northrop and D C Puddy *Nucl Instrum Meth* **94** 557 (1971)

[8] J B A England and V W Hammer *Nucl. Instrum. Meth.* **96** 81 (1971)

[9] V V Avdeichikov *Nucl. Instrum. Meth.* **155** 125 (1978)

[10] P A Walley *Thin Solid Films* **2** 327 (1968)

[11] R Saha and R P Sharma *DAE Symposium on Nuclear Physics (Bombay)* **35B** 448 (1992)